Initial Assessment of Trace Element Exposure in Insectivorous Birds Nesting Near the Kingston Ash Spill

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INTRODUCTION

The retaining wall failure on December 22, 2008, at the Tennessee Valley Authority (TVA) Kingston Fossil Plant (KIF) in Roane County, Tennessee, prompted an investigation into the potential impacts of the released coal ash slurry on insectivorous birds. Coal ash contains trace elements known to pose risks to wildlife health. Tree swallows (*Tachycineta bicolor*) in the area forage on invertebrates including insects emerging from the water bodies impacted by the ash slurry. Five colonies of tree swallows were established near the ash spill in 2009 to determine whether trace elements were being transferred from the ash into the surrounding terrestrial communities. In 2010, the project was expanded to include nine more colonies near the spill site. Results from 2010 were compared among impacted sites, reference sites, and historically impacted sites to examine the impacts of maternal transfer of selenium (Se) and other trace elements at these colonies.

Aerial image of Ash Spill at Kingston Fossil Plant, Roane County, TN.

OBJECTIVES

Objective 1: Examine concentrations of trace elements in tree swallow eggs and nestlings. Concentrations of elements such as selenium and strontium in eggs indicate the amount of these contaminants being maternally transferred to offspring. Hatchlings are fed with insects which include those emerging from nearby aquatic sites, thereby revealing potential bioaccumulation and health risks in this insectivorous species. High concentrations of selenium, like those found in coal ash, have been associated with increased incidence of developmental malformations in avian young.

Objective 2: Conduct a pilot assessment of hatching success and nestling percent survival to day 15 to provide foundational information for a forthcoming effects-based study at the site.

METHODS

Study Sites:
Five hundred and thirty bird boxes were installed to establish colonies at seven sites around the Kingston Fossil Plant and seven locations outside of the plant (including locations downstream and upstream of the potentially impacted areas, two reference locations, and one location with legacy metal concentrations; Figures 1 and 2). Sampling in 2009 and 2010 included collections of eggs and nestlings from a subset of bird boxes.

2009 Study:
- Weekly monitoring of five colonies (81 bird boxes)
  - Goal of 10 eggs collected per site
  - Goal of 10 nestlings collected per site (when possible, nestlings came from boxes where eggs had been sampled)

2010 Study:
- Installation of 500 bird boxes
- Daily monitoring of five previously established sites
  - Goal of 15 eggs collected per site
  - Goal of 15 nestlings collected per site (when possible, nestlings came from boxes where eggs had been sampled)
- Weekly monitoring of nine additional sites
  - Goal of 15 eggs collected per site

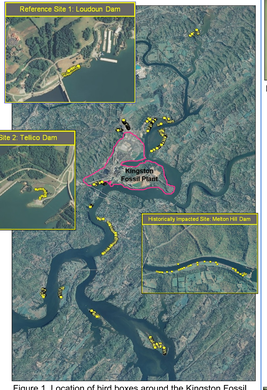

Figure 1. Location of bird boxes around the Kingston Fossil Plant, on the Emory, Clinch and Tennessee Rivers, at 2 reference sites, and at a historically impacted site.

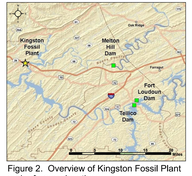

Figure 2. Overview of Kingston Fossil Plant and reference locations.

Eggs were collected (1 egg randomly selected per nest), measured, weighed, and frozen (≤10°C) for analysis. Nestlings (≥15 days old) were euthanized using CO_2, weighed and measured (length of third primary feather and length of tarsus), and then frozen (≤10°C) for analysis.

All eggs and nestlings were shipped to Pace Analytical Services, Inc. and tested for metals: aluminum (Al), antimony (Sb), arsenic (As), barium (Ba), beryllium (Be), boron (B), cadmium (Cd), calcium (Ca), chromium (Cr), cobalt (Co), copper (Cu), iron (Fe), lead (Pb), magnesium (Mg), manganese (Mn), mercury (Hg), molybdenum (Mo), nickel (Ni), potassium (K), selenium (Se), silver (Ag), sodium (Na), strontium (Sr), thallium (Tl), vanadium (V), and zinc (Zn).

Tree swallow nest with eggs in bird box.

Pair of adult tree swallows on bird box.

RESULTS

Eggs

- Clutch sizes ranged from 2-7 eggs (mean clutch size=4.33). One hundred and fifty-five eggs were collected and analyzed in 2010, of which 91 were from the impacted ash spill site.
- Selenium concentrations in eggs differed among sites. Reference sites (Ft. Loudoun Dam, Tellico Dam, Upstream Tennessee River) had significantly lower Se concentrations than impacted sites (Ash Spill Area, Downstream Clinch and Tennessee Rivers) and an historically impacted site (Melton Hill Dam; Kruskal-Wallis, p<0.001, Figure 3).
- The historically impacted site (Melton Hill Dam) has been influenced by at least two upstream facilities disposing of fly ash in settling ponds and thus served as a useful nearby comparison to ash-impacted river conditions.
- Statistical analyses of metals other than selenium have not yet been conducted. However several elements of interest are reported (Table 1). Concentrations of 2 elements (As and V) were below detection limits at all sites. An additional 7 elements (Al, Sb, Be, B, Cd, Pb, Tl), were below detection limits in 95% of eggs at all sites.
- Average hatching success was similar among sites (Kruskal-Wallis, p=0.25, Figure 4), ranging from 84.39 to 93.24% among the sites.
- There was no relationship between egg selenium concentrations and hatching success (linear regression, r^2=0.002, p= 0.73).

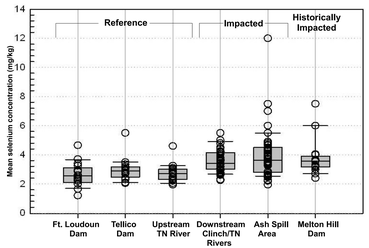

Figure 3. Mean selenium concentrations (mg/kg, dry mass) in eggs at each site, 2010.

Day 15 Nestlings

- Sixty-five nestlings were collected at 15 days post hatch and analyzed. Forty of these were collected from the impacted area (Table 2).
- Selenium concentrations in day 15 nestlings were greater at an historically impacted site (Melton Hill Dam), than at all other sites (Wilcoxon-Mann-Whitney, p≤0.001, Figure 5).
- Statistical analyses of metals other than selenium have not yet been conducted. However several elements of interest are reported (Table 2). Concentrations of 10 elements (Ba, Ca, Cu, Fe, Mn, Mg, K, Na, Sr, Zn) were below detection limits at all sites. One additional element was below detection limits in 98% of eggs at all sites (Mo).
- After removing nests that were predated from our dataset, survival to day 15 did not differ between sites (Kruskal-Wallis, p=0.27), however trends suggest that the reference site had higher survival rates than all other sites (see Figure 6).
- There was no relationship between day 15 nestling survival and selenium concentrations (linear regression, r^2=0.008, p= 0.48).
- Rates of predation ranged from 0 to 33% of boxes at each site. Known predators were raccoons and black rat snakes.

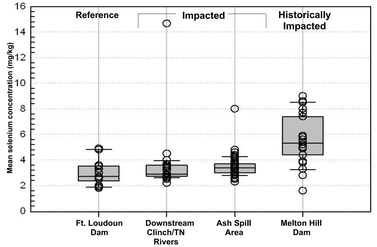

Figure 5. Mean selenium concentrations (mg/kg, dry mass) in nestlings by site, 2010.

Tree swallow nestling approximately 15 days old.

Tree swallow eggs and hatchlings.

Table 1. Average trace element concentration[1] in tree swallow eggs, 2010[2]

Site	n	Se	Sr	As	Hg	V	Cd
Reference	46	2.78 ± 0.11 (0)	7.08 ± 1.22 (0)	0.17 ± 0.01 (46)	0.13 ± 0.01 (12)	0.37 ± 0.06 (46)	0.05 ± 0.01 (45)
Kingston Fossil Plant							
Ash Spill Area	52	3.99 ± 0.23 (0)	7.21 ± 0.72 (0)	0.16 ± 0.01 (52)	0.20 ± 0.01 (23)	0.26 ± 0.01 (52)	0.06 ± 0.004 (51)
Downstream Clinch/TN Rivers	39	3.60 ± 0.14 (0)	6.34 ± 0.77 (0)	0.17 ± 0.01 (39)	0.17 ± 0.01 (34)	0.28 ± 0.02 (39)	0.06 ± 0.003 (39)
Historically Impacted	16	3.78 ± 0.32 (0)	5.43 ± 0.97 (0)	0.16 ± 0.01 (16)	0.12 ± 0.01 (8)	0.26 ± 0.02 (16)	0.04 ± 0.004 (16)
Literature (Impacted)	143	5.88 ± 0.44 (0)[3]	7.68 ± 1.52 (0)[3]	0.39 ± 0.12 (0)[3]	NR	0.21 ± 0.02 (0)[3]	BDL[3]
Literature (Reference)	123	2.69 ± 0.13 (0)[3]	5.06 ± 0.87 (0)[3]	0.46 ± 0.15 (2)[3]	NR	0.23 ± 0.02 (0)[3]	BDL[3]

[1]All trace element concentrations, expressed as milligrams/kilogram (mg/kg) dry mass, are shown as mean ± 1SE with number of non-detects in parentheses.

[2]Predated nest boxes not included.

[3]Bryan et al. 2003. Maternal transfer of contaminants to eggs in common grackles (*Quiscalus quiscala*) nesting on coal fly ash basins.
NR = Not reported.
BDL= Below detection limits.

Table 2. Average trace element concentration[1] in 15 day old tree swallow nestlings, 2010[2]

Site	n	Se	Sr	As	Hg	V	Cd
Reference	10	2.99 ± 0.27 (0)	7.19 ± 0.91 (0)	0.09 ± 0.003 (10)	0.04 ± 0.002 (7)	0.14 ± 0.01 (10)	0.04 ± 0.01 (3)
Kingston Fossil Plant							
Ash Spill Area	25	3.57 ± 0.21 (0)	14.71 ± 2.52 (0)	0.09 ± 0.004 (22)	0.10 ± 0.003 (0)	0.15 ± 0.01 (24)	0.06 ± 0.01 (3)
Downstream Clinch River	15	2.95 ± 0.11 (0)	10.32 ± 0.83 (0)	0.09 ± 0.003(15)	0.09 ± 0.01 (0)	0.14 ± 0.004 (15)	0.05 ± 0.01 (2)
Historically Impacted	15	5.23 ± 0.46 (0)	6.77 ± 0.57 (0)	0.09 ± 0.01(13)	0.06 ± 0.003 (14)	0.22 ± 0.07 (13)	0.08 ± 0.01 (1)

[1]All trace element concentrations, expressed as milligrams/kilogram (mg/kg) dry mass, are shown as mean ± 1SE with number of non-detects in parentheses.

[2]Predated nest boxes not included.

Width of tree swallow egg measured with micrometer.

Location of bird boxes collected with GPS unit.

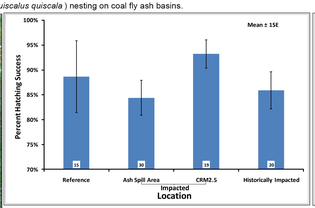

Figure 4. Hatching success of eggs at impacted, reference, and historically impacted sites, 2010 (sample size on each bar).

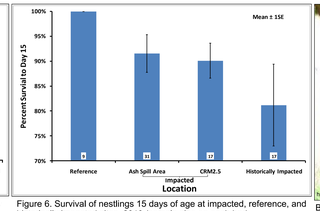

Figure 6. Survival of nestlings 15 days of age at impacted, reference, and historically impacted sites, 2010 (sample size on each bar).

Black rat snake predating bird box.

Length of third primary feather of 15 day old nestling measured using micrometer.

DISCUSSION

Birds are known to readily accumulate and transfer Se to their eggs (Heinz 1996). Initial review of 2010 tree swallow egg monitoring suggests that tree swallows in the vicinity of the Kingston Fossil Plant have experienced exposure to Se derived from coal ash. Mean concentrations of Se in eggs at the ash spill site were significantly higher than at reference sites (Table 1); however, maternal transfer of elevated concentrations of Se only appears to be occurring in a small percentage of the sample population and is confined to nests nearest to the spill area. Although one egg from the impacted site had a Se concentration (12 mg/kg, dry mass) high enough to be associated with adverse reproductive effects (Heinz 1996), in most cases, Se egg concentrations were below those thought to cause reproductive problems in birds.

Few studies have quantified Se in bird eggs near coal ash impacted sites. Bryan et al. (2003) determined that Se concentrations in eggs of common grackles nesting near settling basins had considerably higher concentrations than were observed in our tree swallows. Reference egg concentrations, however, were similar between the two studies (Table 1), and were also comparable to background levels of Se in aquatic bird eggs (Skorupa and Ohlendorf 1991).

High levels of Se concentrations in bird eggs are known to result in hatching failure and teratogenesis (Heinz 1996; Janz et al. 2010). In our pilot effects study, hatching success was generally high and did not differ among locations (Figure 4), but more comprehensive studies are required to definitively determine whether reproduction is impaired at the site. While our initial findings suggest there is no significant relationship between concentrations of Se in eggs and hatching success, Se concentrations cannot be considered in isolation of other trace element concentrations at the site (potential additive or synergistic effects). Evaluation of these other trace elements is ongoing.

Interestingly, Se concentrations of tree swallow eggs were greater than in eggs of other avian species examined in the impacted areas of the site (See Wildlife Overview poster). Lower Se concentrations in the eggs of piscivorous birds suggest that tree swallows feeding on benthic invertebrates are currently at greater risk of exposure to Se than birds in higher trophic levels.

Concentrations of Se in nestlings at day 15 were not significantly different between reference and impacted areas; however, Se concentrations were significantly higher at the historically impacted site (Melton Hill Dam). Melton Hill Dam is downstream of known sources of legacy contaminants on the Clinch River (e.g., Department of Energy facilities on the Oak Ridge Reservation) and provides a local comparison to a system impacted by metals (Cook et al. 1999). Our initial monitoring effort suggests there is no significant relationship between Se concentrations in nestlings and survival to day 15. More rigorous sampling is needed to provide a more robust sample size for determining such relationships and the full suite of trace elements will be considered.

In spring 2011, a full scale reproductive effects-based study will be launched to determine whether the spill is influencing parameters (e.g., hatching and fledging success, return rates of banded birds) important to tree swallow fitness and population viability.

Fifteen day nestling collection.

Burrowing mayflies emerging from the Tennessee River. Mayflies may represent one of the invertebrate prey types that tree swallows ingest.

REFERENCES

Bryan, A.L., Jr., W.A. Hopkins, J. A. Baionno, and B. P. Jackson. 2003. Maternal transfer of contaminants to eggs in common grackles (*Quiscalus quiscala*) nesting on coal fly ash basins. *Archives of environmental contamination and toxicology* 45: 273-277.

Cook, R.B., G.W. Suter II, and E. Riley Sain. 1999. Ecological risk assessment in a large river-reservoir: 1. Introduction and background. *Environmental Toxicology and Chemistry* 18(4): 581-588.

Heinz, G.H. 1996. Selenium in birds. In: Beyer W.N., G.H. Heinz, A.W. Redmon-Norwood (eds). Environmental contaminants in wildlife: Interpreting tissue concentrations. CRC Press, Boca Raton, FL. pp 447-458.

Janz, D.M., D.K. DeForest, M.L. Brooks, P.M. Chapman, G. Gilron, D. Hoff, W.A. Hopkins, D.O. McIntyre, C. A Mebane, V.P. Palace, J.P. Skorupa, and M. Wayland. 2010. Selenium Toxicity to Aquatic Organisms. In: Chapman, P. (ed). CRC Press, Taylor and Francis Group, LLC, Boca Raton, FL. pp 141-231.

Skorupa, J.P. and H.M. Ohlendorf. 1991. Contaminants in drainage water and avian risk thresholds. In: Dinar, Zilberman D (eds) The economics and management of water and drainage in agriculture. Kluwer Academic Publishers, Dordrecht, pp 345-368.

RELATED STUDIES

Emerging benthic invertebrates at the Kingston Fossil Plant Ash Spill are also being tested to explore the potential transfer of trace elements to the terrestrial wildlife communities. The annual summer emergence of burrowing mayflies may provide a potential route for the transfer of metals to terrestrial insectivores.

ACKNOWLEDGEMENTS

The authors would like to thank the following individuals and agencies for their assistance with collecting, processing, and analyzing samples for this study: Wes James, Ken Weisz, Adam Johnson, Travis Walls, Katie Gassaway, Phil Goodrum, Gina Houck, Tim Negley, Mirtha Martin, Jason Brown, Holly LeGrand, Staff at Kingston Fossil Plant, TVA GIS Department, TVA Police, TVA Reality Services, Environmental Standards, Inc., Pace Analytical Services, Inc., Restoration Services, Inc., ARCADIS, Jacobs Engineering, Tennessee Wildlife Resources Agency, and U.S. Fish and Wildlife Services.